

Modular Spectral Inference Framework Applied to Young Stars and Brown Dwarfs

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Know Thy Star - Know Thy Planet

Assessing the Impact of Stellar Characterization on Our Understanding of Exoplanets

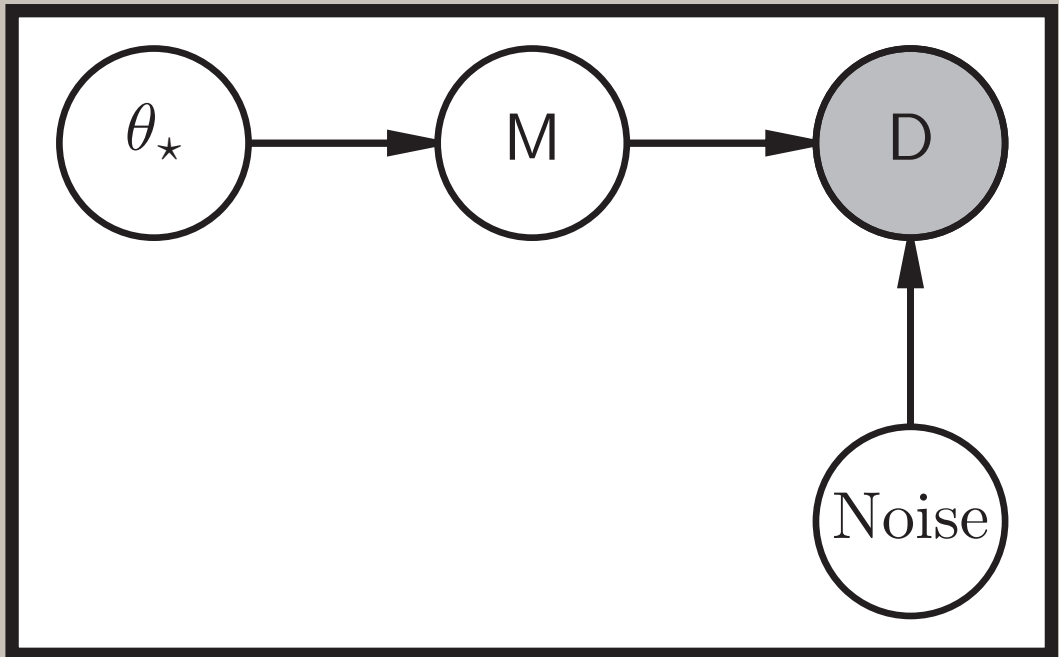
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Perfect Synthetic Spectral Models

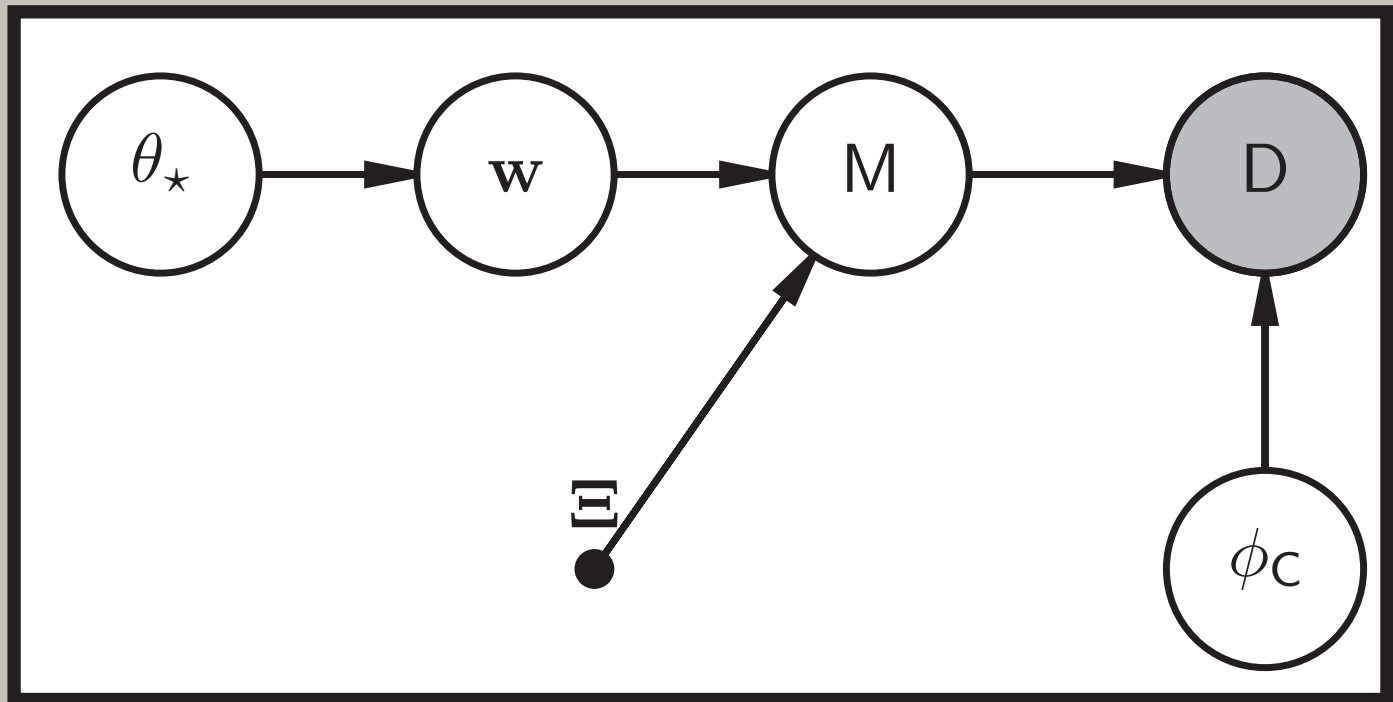
If synthetic spectral models were **perfect**, we could use **forward modeling and statistical inference** to derive accurate stellar parameters for a given observed spectrum.

data spectrum **D**
model spectrum **M**
infers
stellar parameters θ_*



The model spectrum might be hard to compute, and so you could **emulate a grid of precomputed spectra**, and track uncertainty.

spectral emulation weights **w**
precomputed model grid Ξ
covariance matrix ϕ_C

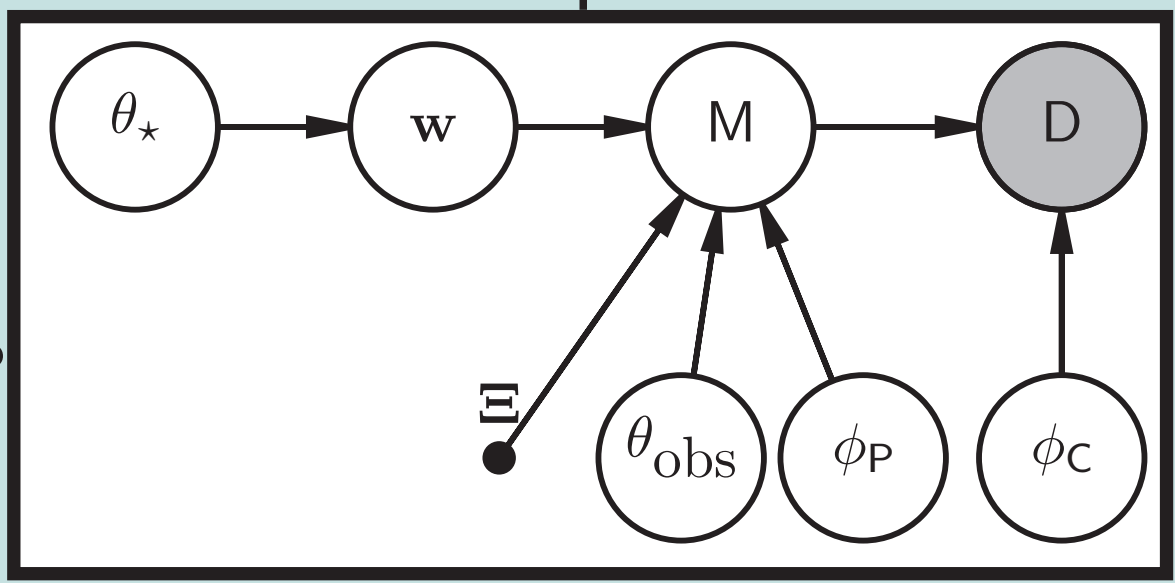


Imperfect Synthetic Spectral Models

github.com/iancze/Starfish

In practice, synthetic spectral models are **imperfect**, causing inaccurate estimates of stellar parameters. Czekala and collaborators (2015) recently introduced the spectral inference framework **Starfish** robust against some common model imperfections.

spectrograph resolution θ_{obs}
wavelength dependent slit losses ϕ_P



intrinsic stellar parameters $\theta_* = \{T_{\text{eff}}, \log g, [\text{Fe}/\text{H}]\}$ [Section 2.1]
extrinsic stellar parameters $\theta_{\text{ext}} = \{v \sin i, v_z, \dots\}$ [Section 2.2]

Emulator [Appendix A]
delivers

reconstruction of model spectrum
model

covariance matrix describing probability of spectra

[Section 2.2]

ϕ_P flexible polynomials multiply model to adjust flux calibration

data

[Section 2.3.1 & 2.3.2]

$\phi_C = \{\phi_{C,G}, \phi_{C,L}\}$
global and local kernels identify and downweight residuals in noise matrix

[Section 2.3.3]

composite covariance matrix is sum of emulator and noise matrices

$C =$

[Section 2.3]

$R = \text{data} - \text{model}$

$$\ln p(D|M) = -\frac{1}{2} (R^T C^{-1} R + \ln \det C + N_{\text{pix}} \ln 2\pi)$$

spectral inference applied to... brown dwarfs

in collaboration with Mark Marley at NASA Ames

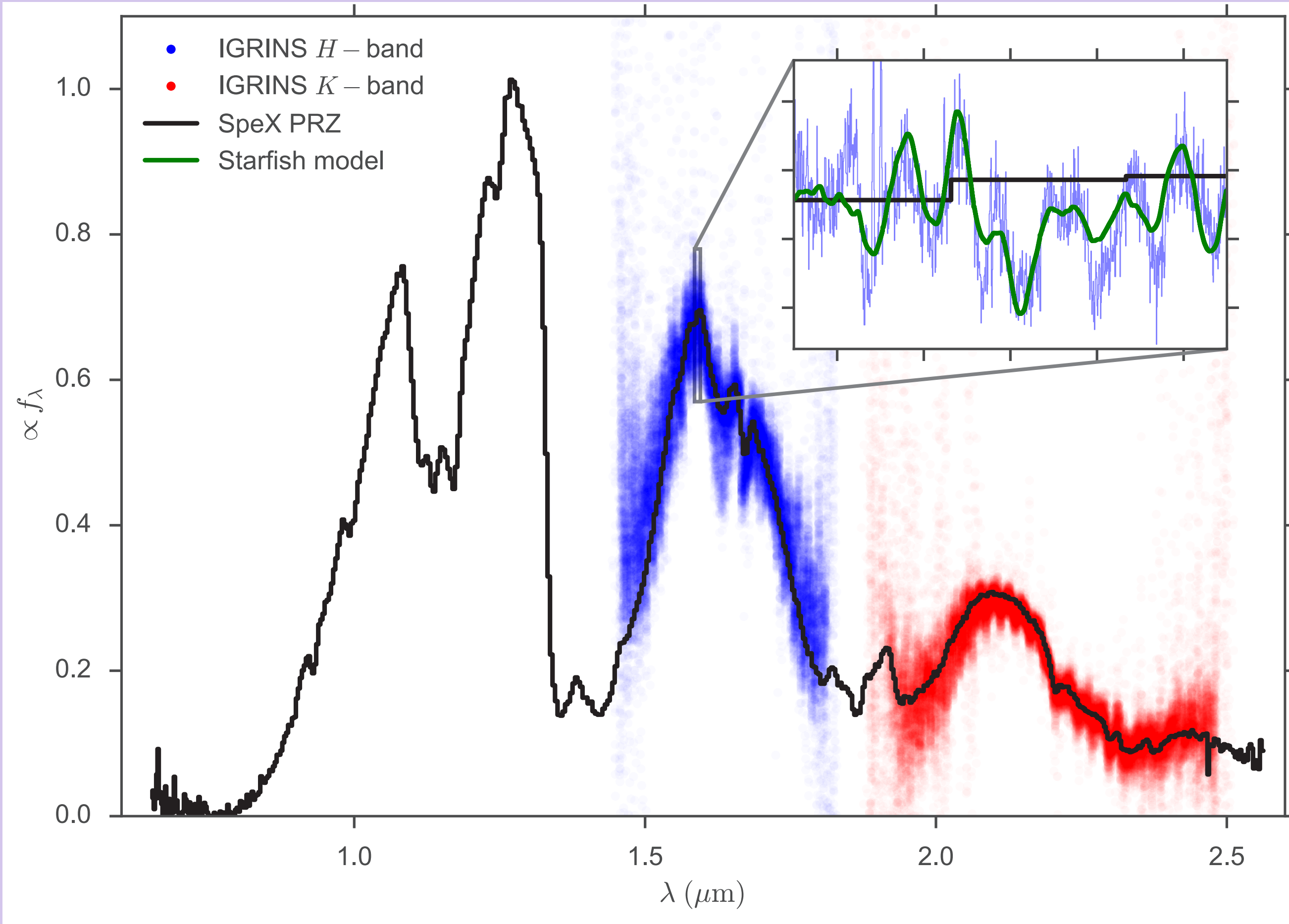
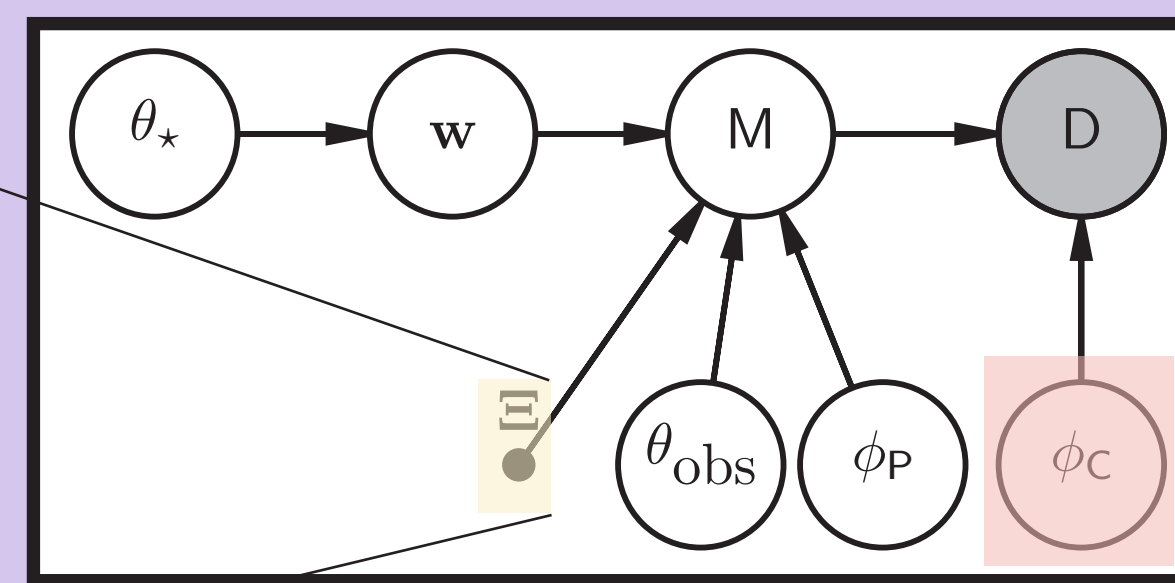


Figure: This T2.5 brown dwarf (courtesy M. Cushing) has an effective temperature less than 1300 K, approaching surface temperatures of young exoplanets. The green line on the inset shows the IGRINS data fit with a single draw from the family of Starfish-derived posteriors. This particular draw has $T_{\text{eff}} = 1275$ K and $\log g = 5.34$. IGRINS is providing the highest fidelity test of models to date.

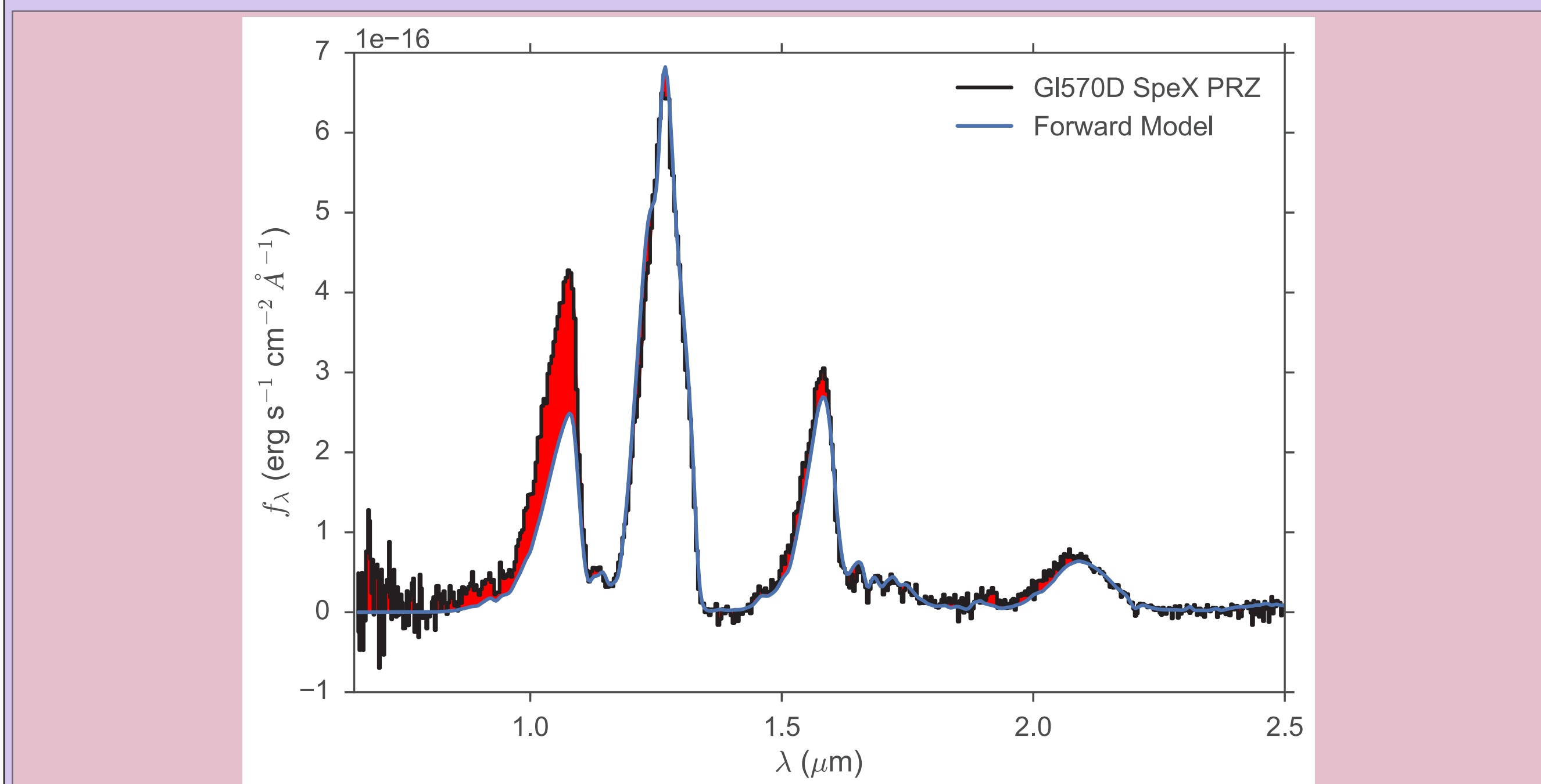
Marley and collaborators have been producing synthetic spectral models of brown dwarfs for over 20 years (Marley et al. 1996, Morley et al. 2014). The newest grid of models, Sonora Bobcat (Marley et al. in prep.), spans a massive multi-dimensional grid:

$200 < T_{\text{eff}} < 2400$ K in 39 steps
 $3.25 < \log g < 5.5$ in 10 steps
 $f_{\text{sed}} = 1, 3$, cloudless
10 steps in $[M/H]$
6 steps in C/O.



The combination of inference with the new Marley et al. models applied to IGRINS spectra will be transformative to accurate fundamental parameter estimation and improvement of atmospheric models for **JWST**.

Figure: Spectral line or bandhead outlier rejection can be built into the Starfish covariance matrix. IGRINS data will provide exceptional feedback to models.



github.com/gully/jammer-G1570D

Immersion Grating Infrared Spectrograph (IGRINS)

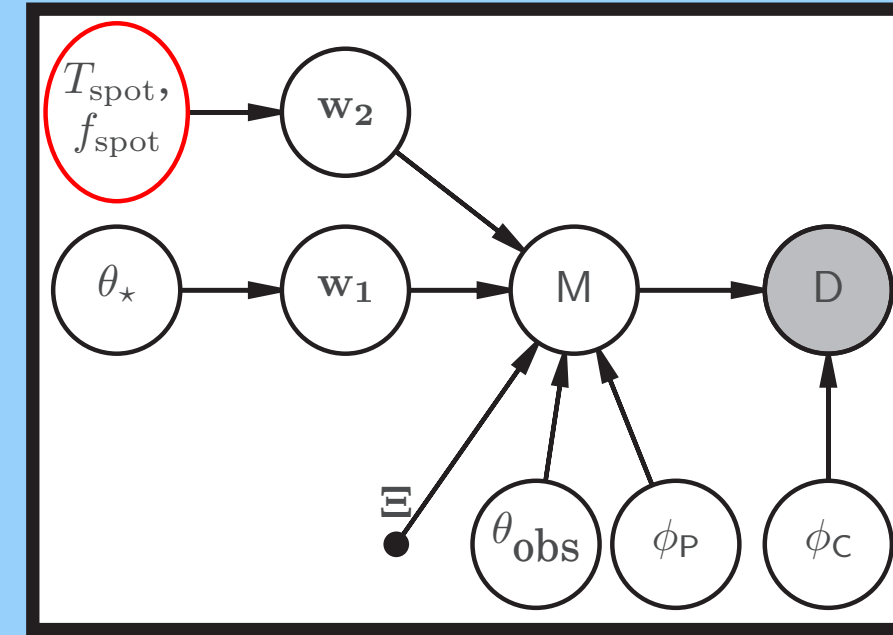
IGRINS provides $R=45,000$ spectral resolution across the entire H- and K- near IR windows in a single shot. Its high spectral grasp and high efficiency stem from a custom Silicon Immersion Grating (Gully-Santiago et al. 2012) and VPH cross dispersers. The instrument is currently on the Discovery Channel Telescope, but will move to Gemini South starting in April 2018.

young stars

in collaboration with Greg Herczeg, Garrett Somers, et al.

I extended Starfish to support two component mixture models, such as:

1. spectroscopic binary stars
2. "veiling" from circumstellar disk emission
3. **photospheric emission from starspots** ($T_{\text{spot}}, f_{\text{spot}}$)



Young stars (< 10 Myr) possess large starspots, evinced in their sinusoidally varying lightcurves from ASAS-SN, **Kepler/K2**, and the ROTOR program (Grankin et al. 2008). The starspots possess finite, non-zero temperatures T_{spot} , cooler than their ambient photosphere. If starspots are large enough, they can be measured spectroscopically, especially in the near-IR with IGRINS.

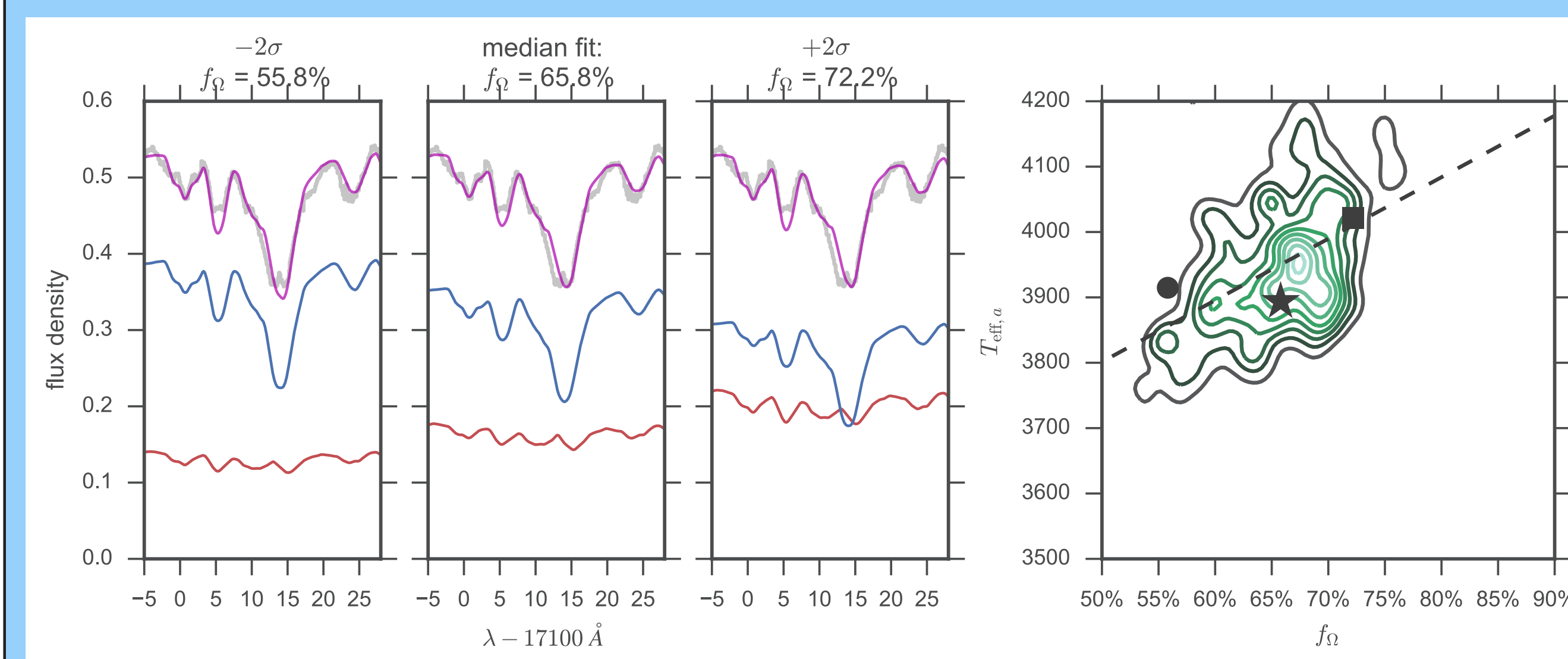
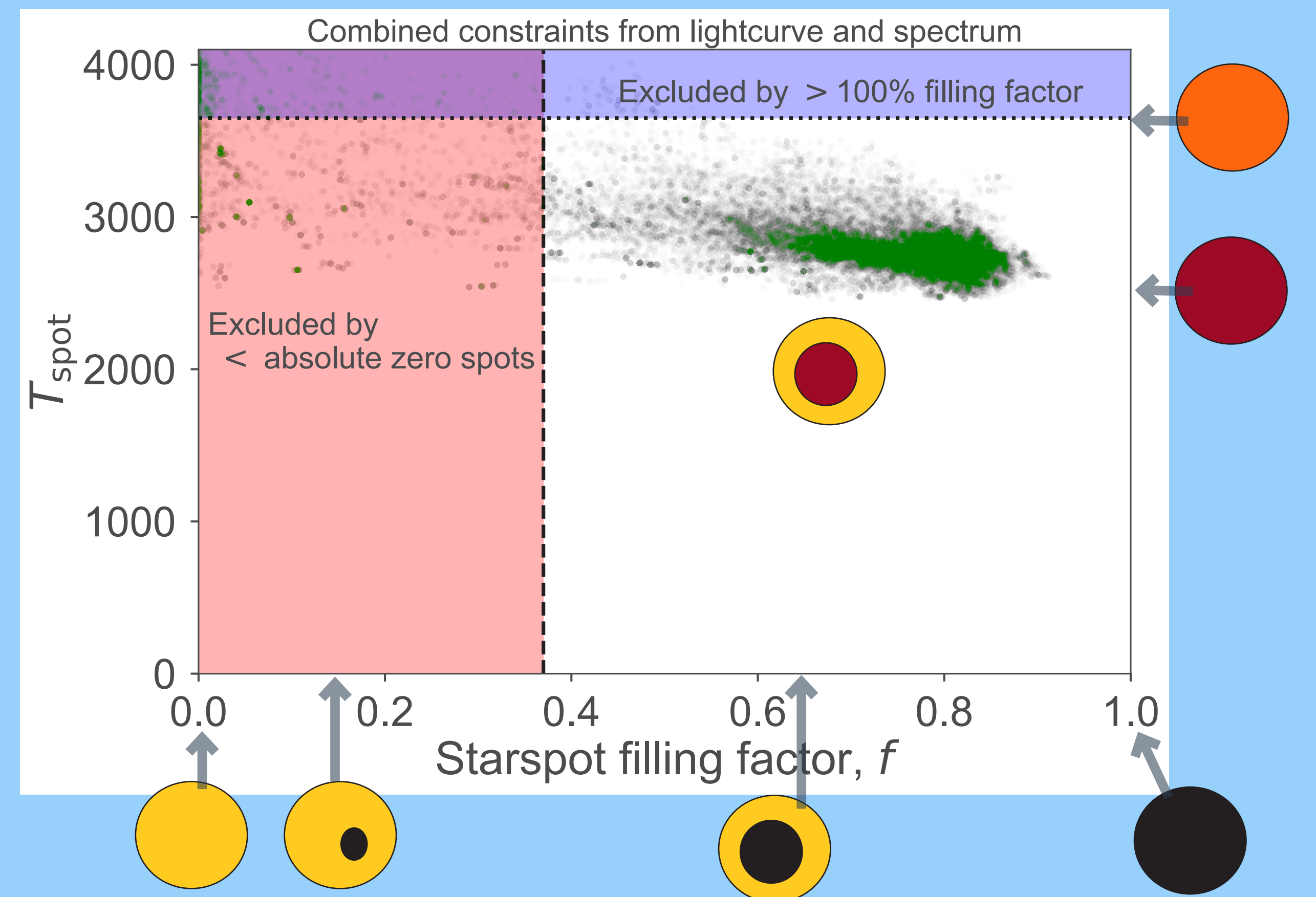


Figure: A portion of the IGRINS spectrum of LkCa 4, a heavily spotted weak-lined T-Tauri Star in Taurus. Three **composite draws** from the Starfish-produced posterior fit the IGRINS data to within the uncertainties. The composite comprises two mixture models components of **starspot cool photosphere** and **ambient warm photosphere**. The **posterior PDF** for this spectral order yields a filling factor of greater than 50% starspot coverage, and ambient photosphere temperatures consistent with optical measurements.



Lightcurve shapes are degenerate with geometrical projection effects. For example, pole-on stars show zero starspot-induced rotational modulation. In the **Figure** above, combined constraints from lightcurves and IGRINS spectra break degeneracies. Posterior draws fill a region with $T_{\text{spot}} \sim 2800$ K and $f_{\text{spot}} \sim 0.8$.

github.com/BrownDwarf/welter

What's new at K2 GO office

Guest Observer (GO) Cycle 6 proposals are due by October 12. Star Clusters Workshop: January 16-18, 2018 Boston University.

- **New:** Tutorials for data mining K2 metadata
Fine Guidance Star (FGS) data on MAST
- **Updated:** PyKE is now pyraf-free; python, CLI, and API
- **Experimental:** Supernova lightcurves from difference imaging
Infer color changes from PSF chromaticity
Tools for PSF photometry adapted from FFIs
- **Coming soon:** Podcasts and screencasts